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Study on mechanical properties of mortars containing steel shot and sea sand as fine aggregate replacement

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Abstract. In this study, the use of solid waste known in the metallurgical market as steel shot that is generated in the production of metallic elements has been analyzed. Normally the destination of this solid waste is the sanitary landfills of the cities or the security cells since it is classified as hazardous waste. In addition, the use of materials with high availability and that were not previously used in the construction industry, such as sea sand was used in the manufacture of mortar cubes as a fine aggregate. A granulometric analysis of each of the filling materials followed by the casting of 63 mortar cubes with four different fine aggregate replacement ratios (0%, 30%, 70% and 100%) were carried out. After the curing period, the compressive strength and the weight of the resulting mortars have been determined. The results from this study indicated that by completely replacing the fine aggregate with the steel shot waste the density and the compressive strength of the resulting mortars were increased, which indicates that this new material can be used in the construction industry.

1. Introduction

The increase in the number of inhabitants worldwide, as well as the development of industrialization processes, mainly in the developed countries, which generate a high demand for raw material to maintain its production and commercialization processes [1], brings with it the increase of waste production and exploitation of natural resources to meet the basic needs generated by the high demand for new infrastructure [2]. The current consumer mentality encouraged the generation of larger volumes of waste, which, for the most part, are destined to final disposal areas to be stored. Among the main activities that have been influenced by the increase in population, and which in turn requires a greater amount of resources to be able to be carried out, is construction. The construction of new structures to meet the basic needs of the growing population, such as housing, brings with it an increase in the exploitation of natural resources, which generates an accelerated reduction of their availability in the environment. Current constructions are made of different types of materials, with concrete and mortar being the most widely used mixtures worldwide, becoming the second most consumed element on the planet, after water [3].

It is easy to show this increase or growth in the demand for new materials in developing countries. In this study, Colombia will be used as an example, whose figures in the first quarter of 2017 indicate that the construction sector increased by 3.3 % compared to the same quarter of 2016 (according to the Civil Works Investment Indicator of the National Administrative Department of Statistics (DANE)

[4]. This growth is evidenced by the increase in construction policies implemented by the last governments and by the need to overcome existing oversupply, mainly in corporate and hotel construction [5]. Taking into account this construction boom, the production of cement (the main component of the mortar) and the exploitation of the raw material required for its elaboration increased. This assumption is based on the upward trend in cement production in Colombia, which increased from 852,100 tons in 2012 to 976,900 tons of production in 2017 [6], directly increasing the exploitation of quarries for the extraction of stony materials (fine and coarse aggregate).

Nowadays, research has been carried out to find alternatives for concrete production, implementing new resources, mainly waste generated by the activity of the human being.

Analysis as the use of e-plastic waste as a replacement for the coarse aggregate [7], or some studies about the sand replacement for different waste materials like quarry waste [8] or iron ore tailing [9] represent the need to reduce polluting elements that affect the environment. On the other hand, some studies have discovered the possible replacement for cement with other kinds of waste in the concrete, like ceramic waste [10] or marble and granite waste [11], among others.

In order to reduce the negative impact caused by the uncontrolled generation of solid waste in industrial steel cleaning processes, these materials have been used in the preparation of mortar mixtures [12]. Also, the use of raw material with wide availability, such as sea sand, encouraged the realization of studies that allow its application in construction [13].

Regarding industrial waste, several studies have been carried out and then some of the most relevant and interesting for this research will be shown: materials such as residual sand foundry have been studied to analyze their effects on concrete mixtures as a replacement for the fine aggregate. This is the case of the replacements of 10%, 20%, 30%, 40% and 50% of the fine aggregate by residual sand from aluminum industries, being a viable option to reduce the exploitation of fine aggregate required for the manufacture of concrete [14]. On the other hand, it has been found that by including residual sand from cast iron in concrete mixtures, an increase in water absorption is evidenced, which generates a decrease in the compressive strength in the specimens tested every time it increases the amount of the residual sand found in the mixture [15], for this reason, is not recommending exceeding a 20% replacement [16]. In the same way, in others studies that have used residual sand from cast iron and that have used replacements from 15% of fine aggregate, the compressive strength improves [17].

Another waste with conditions very similar to the one used in this project is steel slag, which is a waste generated in the industries dedicated to the manufacture of iron and steel [18]. The application of the replacement of this waste by the fine aggregate above 50% in the concrete reduces the workability of the mixture; however, by implementing replacements between 15% and 30%, improvements in the compressive strength of concrete are evidenced [19]. The steel slag replacements above 30% have shown a reduction in the compressive strengths obtained compared to the control mixture [20].

Based on the above, the present study aims to find an alternative to reuse a metallurgical by-product (blast residue) and to implement sea sand in the manufacture of resistant mortars according to ASTM C109M [21] evaluating the mortar resistance that includes steel-shot as a replacement of the fine aggregate, in order to reduce the obvious environmental impact generated by the erroneous disposal of this waste in landfills.

2. Methodology

The present research is of experimental quantitative type. The filling materials (sea sand, rock sand and metallic grit residue) were obtained in different ways. The sea sand was obtained in the excavations carried out in the construction of the Monticello condominium, in the vicinity of the township of Salgar (Atlántico-Colombia). Regular sand was acquired in the city of Barranquilla (Atlántico-Colombia), and finally the residue of metallic grit originated from the Polyuprotec plant located in the municipality of Malambo (Atlántico-Colombia), which is generated in the process of cleaning oxides and paintings of metallic elements. The cement used was a general use type from the cement company Argos. The chemical parameters of the cement used indicates that it has a maximum percentage [%] of magnesium oxide (MgO) of 6 and a maximum percentage [%] of sulfur trioxide (SO3) of 3.5, thus fulfilling the requirements of ASTM C-1157 Type UG. The procedures stipulated in the international standard ASTM C33 [22] were taken to obtain the gradation of fine aggregates (sea sand and conventional sand or AM and AP for its acronym in Spanish) and alternative material (granular residue (RG for its acronym in Spanish)), as well as the values of the fineness modulus of each filling material.

Subsequently, two different mortar mixtures were made, one mixture with AM and one with AP (defined as "control" (without replacement)), as stipulated in ASTM C109M [21]. With the purpose of mix with AM, taking into account the granulometric behavior found and the fineness modulus calculated, it was necessary to sieve approximately 10000 g of the material to comply with the gradation established in the standard and to make comparisons with the cubes elaborated with AP. With the mentioned mixtures, mortar cubes were made (Figure 1) by replacing the fine filler material with RG in the following percentages: 30%, 70%, and 100%. The replacement of the fine aggregate by RG in the defined percentages was carried out by weight [g], taking the retained material in each sieve, established in ASTM C109M [21] and performing the respective AM or AP replacement by RG. Following the established in the same standard, the relation water/cement used is 0.48. Subsequently, the cubes were tested at 7, 14 and 21 days, in order to make comparisons of the values of the obtained resistances.

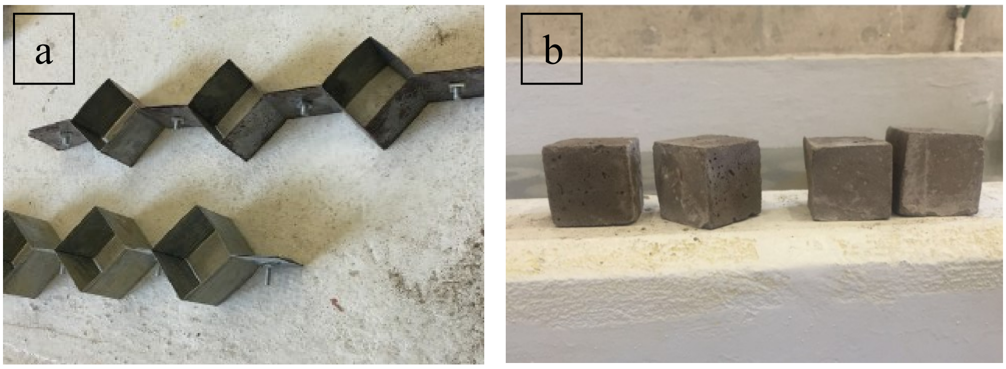

Figure 1. Ilustration of the a) cubes molds and the b) casted mortars cubes.

The amount of chloride ion was determined for sea sand (AM) by the Standard Methods of the American Public Health Association (APHA). The result obtained was 14.7 mg / L, for a 2: 1 solution.

After the 63 cubes with the different replacements were tested, we proceeded to perform the analysis of the results obtained, plotting the compressive strengths in MPa to compare which one is the optimal mixture based on the weight versus compressive strength.

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3. Results and Discussions

3.1 Granulometric analysis

The graphs related to the granulometry of the fine materials and the residue used for the elaboration of the mortar cubes according to ASTM C109M [21] are presented in Figure 2, to calculate the fineness modulus of each material and corroborate that the values obtained are within the range established by ASTM C33 [22].

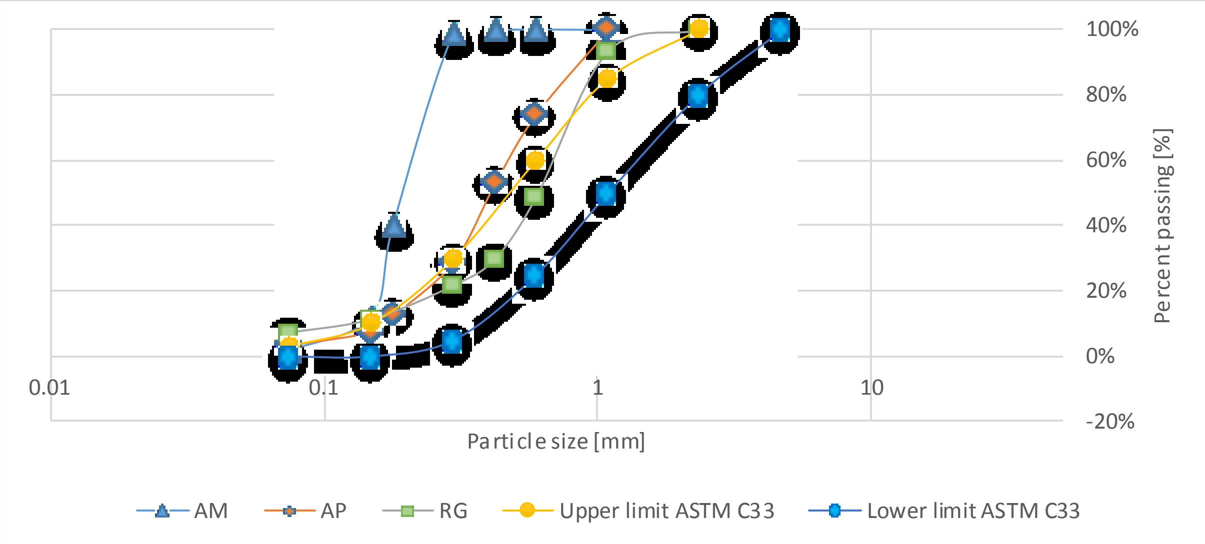

Figure 2. Fine aggregate granulometric curves.

Analyzing Figure 2, the verticality of the graph representing the AM indicates that the granulometry or distribution of the materials is mostly concentrated between the No. 80 and 100 sieves (292.2 g and 140.7 g respectively) showing homogeneity of the particles of the sample. In contrast, a more varied behavior was identified in the samples of AP and RG, these granulometries being the most acceptable for the formation of mortars and concretes, according to ASTM C33 [22], evidencing that 51% of the granular residue was retained between the Sieves No. 16 and No. 30.

Taking into account the granulometric behavior and the amount of material retained per sieve, the fineness modulus of each of the aggregate samples (AM, AP and RG) (Table 1) was calculated. The fineness module (MF) is a value that allows having an approximation of the level of fineness (thickness) that owns the material used, important data to analyze subjects of water demand in the mixtures.

Table 1. Fineness Modulus obtained for each of the aggregates.

Fine aggregate	Fineness Module [FM]
Sea Sand	1.5
Conventional sand	3.2
Granular residue	2.9

With the fineness modulus calculated for each material, a comparison was made with the ASTM C33 [22] acceptable values, which indicates that, for use of fine aggregate in mortars and concretes, the values of the fineness module must be within the range of 2.4 and 3.0. On the other hand, the RG, with a modulus of fineness of 2.9, is in the range acceptable by the norm and literature found, where it is established that one of the characteristics that allows the high resistance of concrete and mortars is that its modules of fineness are close to 3.00, avoiding homogeneities in the granulometric classification [23], affirmation that favors the use of the RG that presents a modulus of fineness of 2.9. However, AM with a modulus of low fineness, generates the need to include larger amounts of water in the mixtures so that the molten cubes handle the same consistency [24].

3.2 Compressive strength
In total 63 mortar cubes were molded, distributed as follows: 9 cubes using only AM as filling material, 9 cubes using AP only, 9 cubes using RG only and 36 cubes, replacing the implemented fine aggregate (AM or AP) with RG. In Table 2, the quantities of material used for each of the constituted mixtures are presented, corresponding to both AP-processed and AM-processed cubes. Taking into account the granulometry required by the standards [25-26], a sieving was performed to comply with the gradation of the fine aggregate to be used in the elaboration of the mortar cubes, for both the AM and AP controls, as well as the cubes that have thin material replacement. The water/cement ratio was 0.48 for all the mixtures following the amounts of material established by ASTM C109M [21].

Table 2. Fine material quantity for control cubes and cubes with replacement.

	0% replace [Control]	30% replacement		70% replacement		100% replacement
	Sand [AP-AM]	Sand [AP-AM]	Granular residue	Sand [AP-AM]	Granular residue	Granular residue
Sieve [No.]	Amount Withheld [g]					
16	0	0	0	0	0	0
30	41	29	12	12	29	41
40	603	422	181	181	422	603
50	1056	739	317	317	739	1056
100	362	253	109	109	253	362
Total	2062	1443	619	619	1443	2062

Subsequently, the measurements of the dimensions and weights of each of the cubes (high, width, length, weight) were taken employing a king's foot and a digital balance. The cubes were tested in the compression test machine, as shown in Figure 3. The results of the characterization and test results under compression are presented in Table 3.

Table 3. Weights and resistances of mortar cubes with different replacement percentages.

	Days of curing	0% (Control)		30%		70%		100%	
		Weight [g]	Resistance [MPa]	Weight [g]	Resistance [MPa]	Weight [g]	Resistance [MPa]	Weight [g]	Resistance [MPa]
Sea-sand	7	273.8	8.3	300.5	12	330.0	17.8	415	18
	14	294.8	10.9	293.6	10.9	349.2	12.4	409	23.2
	21	290.7	13.2	320.9	15.6	340.9	14.6	383	26
Regular sand	7	304.7	11.9	345.5	15.3	408.0	17.5	415	18
	14	316.0	12.1	349.7	12.9	423.7	29.1	409	23.2
	21	304.0	12.38	341.5	21.7	439.5	26.9	383	26

Figure 3. Cubes tested with rock-sand and 70% of replacement by waste of shot.

Having the results of the compression tests of the cubes, a comparison was made between the resistances obtained between AM mortar cubes with 0% replacement and mortar cubes made with AP with 0% replacement, as shown in Figure 4.

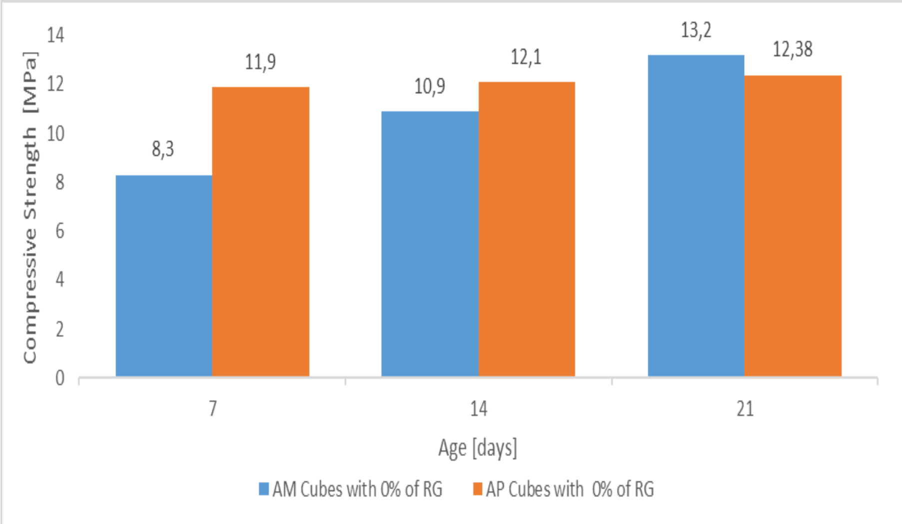

Figure 4. Comparison of compressive strength obtained in mortar cubes made with AM and AP.

As can be seen in Figure 4, it is evident that, after 21 days of curing, the mortar cubes constituted by AM have higher resistances (13.2 MPa). Nevertheless, it is identified that the cubes with this material, in the first days of curing, have inferior resistances to the cubes elaborated with AP, requiring more time to reach the expected resistances.

Then, the behavior of the compressive strengths obtained in each mix design (AM or AP) with their respective replacements by RG, as shown in Figures 5 and 6, was identified.

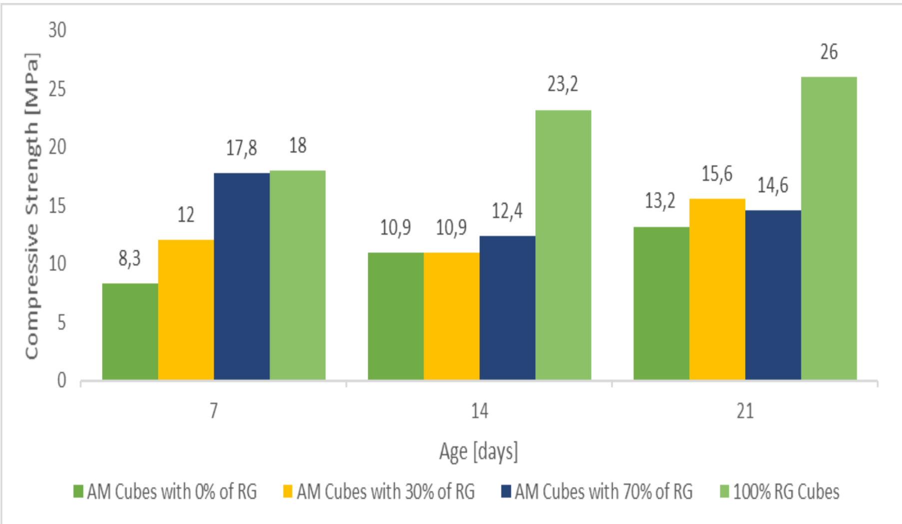

Figure 5. Compressive strength obtained in the mixture design with AM.

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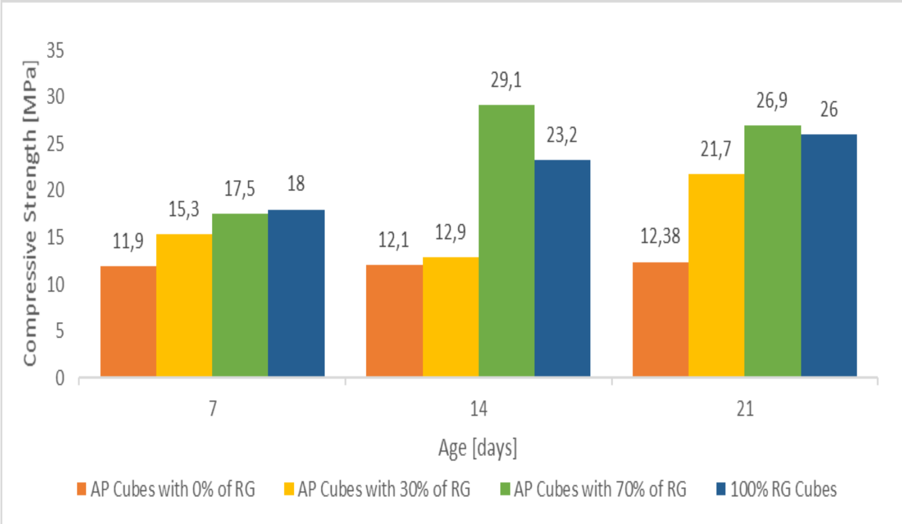

Figure 6. Compressive strength obtained in Mixture Design with AP.

As can be observed in the results of Table 3 and represented in Figures 4-6, the higher resistances were obtained in the cubes with 70% replacement of the fine aggregate by RG, in the mixture with AP (26.9 MPa). In contrast, the cubes with less resistance were those obtained with the mixture of AP without replacement by RG (12.38 MPa).

Analyzing the resistance obtained in the different days of curing, there are variations in the values obtained in the mixtures that present 30% and 70% replacement of the filling material by RG, presenting reductions of the resistances at 14 days of curing and increments again at 21 days. However, it is identified that in the two mixtures used in the present investigation (AM and AP) the obtained resistances, applying any percentage of replacement by RG, generate resistances superior to the control cubes. On the other hand, the results obtained are inverse to the resistances found when using mixing designs with other waste, like steel slag [18] or residual sand foundry [16], where better results are obtained with low replacement percentages. The aforementioned facilitates the reduction of the quantities of waste of existing shot when it is required in greater volumes for the elaboration of mortars, reducing the amount of this waste in safety cells.

On the other hand, as the percentage of replacement of the fine aggregate by RG increases, the weight also increases, due to the difference of densities that appear between the sands and the GR. However, it is important to note that the weights decrease as they increase the days of curing the mortar, which generates a new research topic to find the cause of this weight loss. Due to this, these mortars become very dense and are not suitable for tall constructions, due to the great weight that would be contributing for purposes of dimensioning of foundations and for the system of seismic resistance to lateral load (lateral loading is directly related to the mass of the structure). Therefore, we are looking for lighter constructions to avoid oversizing by high self-weight [27].

4. Conclusions and Recommendations

In the present investigation, it can be concluded that the granular residue (RG) complies with the Colombian normative requirements of granulometry and compressive strength for its use as mortar filling material. Concerning the compressive strength obtained in the cubes with different fine aggregates, it is recommended, in future investigations, to analyze the reasons for differences in the obtained values of resistances, because, granulometrically, both mixes are standardized according to the established in the norm ASTM C778 [28], deducing that this difference is due by different parameters than the mentioned one.

Finally, the use of RG could be proposed for prefabricated products on an industrial scale, with a high compressive strength and at a lower cost to the market, such as; Separator cases on tracks, containment structures such as gabions, foundations for tanks or silos, including walls and/or slabs for protection against gamma rays or x-rays. However, due to the density of the elements with 100% replacement percentages, their use is not very feasible for elements such as beams or columns because they would increase the dead load of the buildings. For foundation topics, the relationship between strength and size of foundations could be analyzed to find possible benefits of using materials, such as GR, in the concrete to be used. Likewise, it is recommended to analyze the effects that the foundations can generate with RG of steel on the ground and the possible effects that this residue can generate on the steel inside the structure, to validate in environmental and structural issues the application of this new material in construction.

References

[1] United Nations 1992 United Nations Conference on Environment and Development Río de Janeiro, Brazil, 3 to 14 June 1992

[2] Silva, D., Gameiro, F., and de Brito, J. 2013 Mechanical Properties of Structural Concrete Containing Fine Aggregates from Waste Generated by the Marble Quarrying Industry *In Journal of Materials in Civil Engineering* **26** https://doi.org/10.1061/(asce)mt.1943-5533.0000948

[3] Meyer, C. 2009 The greening of the concrete industry *Cement and Concrete Composites* **31** 601–605. https://doi.org/10.1016/j.cemconcomp.2008.12.010

[4] DANE 2017 Indicador de inversion en Obras Civiles. Retrieved June 23, 2017, from https://www.dane.gov.co/index.php/estadisticas-por-tema/construccion/indicador-de-inversion-en-obras-civiles

[5] Flórez, G. 2016 Así está la construcción en Colombia | *Economía | Portafolio*. Retrieved June 15, 2017, from http://www.portafolio.co/economia/asi-esta-la-construccion-en-colombia-501002

[6] Bogotá DC 2017 Comunicado de Prensa Estadísticas de Cemento Gris (ECG)

[7] Sabău, M., and Vargas, J. R. 2018 Use of e-plastic waste in concrete as a partial replacement of coarse mineral aggregate *Computers and Concrete* **21** (4) 377–384. https://doi.org/10.12989/cac.2018.21.4.377

[8] Gómez-Balbuena, D. N., López-Lara, T., Hernandez-Zaragoza, J. B., Ortiz-Mena, R. G., Navarro-Rojero, M. G., Horta-Rangel, J. and Rojas-Gonzalez, E. 2018 Polymer-Cement Mortar with Quarry Waste as Sand Replacement *Advances in Materials Science and Engineering* 1–10. https://doi.org/10.1155/2018/3984835

[9] Chavan, R. R., and Kulkarni, D 2013 Performance of Copper Slag on Strength Properties As Partial Replace of Fine Aggregate in Concrete Mix Design *Int. J. Adv. Engg. Res. Studies* **II**-IV 95–8

[10] Karthikeyan, B. and Dhinakaran, G. 2017 Strength and durability studies on high strength concrete using ceramic waste powder *Structural Engineering and Mechanics* **61** (2) 171–181

[11] Ghorbani, S., Taji, I., Tavakkolizadeh, M., Davodi, A., and Brito, J. 2018 Improving corrosion resistance of steel rebars in concrete with marble and granite waste dust as partial cement replacement. *Construction and Building Materials* **185** 110–119. https://doi.org/10.1016/j.conbuildmat.2018.07.066

[12] Thomson Gale, M. F. S., and ruiz, D. D. P. 2011 Revista educación en ingeniería *Revista Educación en Ingeniería* **6**

[13] Huiguang, Y., Yan, L., Henglin, L., and Quan, G. 2011 Durability of sea-sand containing concrete: Effects of chloride ion penetration *Mining Science and Technology* **21** 123–127. https://doi.org/10.1016/j.mstc.2010.07.003

[14] Ganesh Prabhu, G., Hyun, J. H., and Kim, Y. 2014 Effects of foundry sand as a fine aggregate

in concrete production *Construction and Building Materials* **70** 514–521. https://doi.org/10.1016/j.conbuildmat.2014.07.070
[15] Khatib, J. M., Herki, B. A., and Kenai, S. 2013 Capillarity of concrete incorporating waste foundry sand *Construction and Building Materials* **47** 867–871. https://doi.org/10.1016/j.conbuildmat.2013.05.013
[16] Basar, H. M. and Deveci Aksoy 2012 The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and microstructural characteristics of ready-mixed concrete *Construction and Building Materials* **35** 508–515. https://doi.org/10.1016/j.conbuildmat.2012.04.078
[17] Singh, G., and Siddique, R. 2012 Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete *Construction and Building Materials* **26** (1) 416–422. https://doi.org/10.1016/j.conbuildmat.2011.06.041
[18] Dash, M. K., Patro, S. K., and Rath, A. K. 2016 Sustainable use of industrial-waste as partial replacement of fine aggregate for preparation of concrete – A review *International Journal of Sustainable Built Environment* **5** (2) 484–516. https://doi.org/10.1016/j.ijsbe.2016.04.006
[19] Qasrawi, H., Shalabi, F., and Asi, I. 2009 Use of low CaO unprocessed steel slag in concrete as fine aggregate *Construction and Building Materials* **23** (2) 1118–1125 https://doi.org/10.1016/j.conbuildmat.2008.06.003
[20] John, A. and John, E. 2013 Study on the partial replacement of fine aggregate using induction furnace slag *American Journal of Engineering Research* **4** 1–5
[21] ASTM 2016 ASTM Standard C109M *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars*
[22] ASTM International 2018 ASTM C33M-18 *Standard Specification for Concrete Aggregates* https://doi.org/10.1520/C0033_C0033M-18
[23] Carpio, C. 2007 Concretos de alta resistencia dentro de los no convencionales *Administración para el diseño* **16**
[24] Sanchez de Guzman, D. 2001 Tecnología del Concreto y del Mortero *Bhandar Editores ltda, Ed.* Bogotá
[25] ASTM 2003 Standard Specification for Concrete Aggregates
[26] ASTM 2006 Standard Specification for Standard Sand
[27] Joel Novas Cabrera, I. A. (n.d.). 2010 Sistemas constructivos prefabricados aplicables a la construcción de edificaciones en países en desarrollo *Universidad Politécnica de Madrid*
[28] ASTM International 2017 ASTM C778-17 *Standard Specification for Standard Sand* **6** https://doi.org/10.1520/C0778-17